U. S. NAVAL SUBMARINE MEDICAL CENTER

Submarine Base, Groton, Conn.

REPORT NUMBER 500

STUDY OF AIR EMBOLISM AND EXTRA-ALVEOLAR ACCIDENTS ASSOCIATED WITH SUBMARINE ESCAPE TRAINING 1956 TO 1966

by

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Bureau of Medicine and Surgery, Navy Department
Research Work Unit MR005.04-0055.10

Released by:

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COMMANDING OFFICER
U. S. Naval Submarine Medical Center

17 August 1967

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SUBMARINE MEDICAL RESEARCH LABORATORY

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SUMMARY PAGE

PROBLEM

To bring up to date a review of over-pressurization accidents occurring as a result of submarine escape training at the Escape Training Tank, at the Naval Submarine Base at Groton, Connecticut. The previous report reviewed all such accidents occurring during the period 1928-1957.

FINDINGS

Twenty-three such cases are presented, with discussion of the reasons. A synopsis of each accident case is presented in the Appendix and its relation to the total number of men trained by the various methods.

APPLICATION

The information presented in this report will be valuable to medical officers specializing in submarine medicine and will contribute to increased safety and effectiveness in the submarine escape training procedures.

ADMINISTRATIVE INFORMATION

This investigation was conducted as a part of Bureau of Medicine and Surgery Work Unit MR005.04-0055—Pathological Physiology of Air Embolism and Decompression Sickness. The present report was approved for publication on 17 August 1967 and has been designated as Submarine Medical Center, Submarine Medical Research Laboratory Report No. 500. This report is No. 10 on the Work Unit shown above

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ABSTRACT

This report is an extension of Moses' study of casualties resulting from submarine escape training during the period 1928-1957. A total of 23 additional over-pressurization accidents are presented, along with discussion as to whether the increased accident rate following introduction of buoyant ascent runs is real or apparent.

Reason for the high accident rate with the Steinke Hood when this type of training was first introduced are advanced, and reasons are given for the occurrence of accidents in re-qualifiers as opposed to the student trainees. Some of the casualties are attributed to lung abnormalities leading to pulmonary air-trapping, which causes symptoms to develop after seemingly successful training runs.

STUDY OF AIR EMBOLISM AND EXTRA-ALVEOLAR ACCIDENTS ASSOCIATED WITH SUBMARINE ESCAPE TRAINING 1956 TO 1966

INTRODUCTION

The intent of this report is to up-date through December 1966 a review of over-pressurization accidents occurring as a result of submarine escape training at the Escape Training Tank, Naval Submarine Base New London, at Groton, Connecticut. Discussion will be primarily in regard to the production of air embolism and extra-alveolar air following the two methods of submarine escape currently being taught, buoyant ascent with free-breathing, and buoyant ascent using the Steinke Hood. Description of these two methods are given in another report (1).

BACKGROUND

In 1957, Moses, in reviewing the incidence of air embolism in all submarine escape training, found forty-four cases to have occurred from 1928-1957, resulting in eight fatalities. In addition, during this time there were twenty-two cases involving the production of extra-alveolar air, for a total of sixty-six over-pressurization accidents. Incidence records for accidents were calculated by estimating that approximately 250,000 runs had been made at the two U. S. Navy and one Royal Navy Training Tank and are given in reference (2).

Of the 66 cases, thirty casualties, four of which resulted in fatalities, occurred at the New London training facility. All but two of those thirty occurred when using older escape techniques, the submarine escape apparatus or "Momsen Lung" and free ascent. The interested reader is directed to the above reference for a description of both techniques.

The remaining two air embolism cases occurred as a result of buoyant ascent training. This type of training was introduced in 1956, shortly before the writing of the first report. Since that report, an additional 17 over-pressurization accidents have occurred, 12 as a result of buoyant ascent training and four as a result of free breathing, buoyant ascent training, which was introduced to Submarine presonnel in 1963. In addition, one case (in 1956) resulted from a free ascent.

The total number of cases of both air embolism and extra-alveolar air production, such as pneumothorax, pneumopericardium, mediastinal, and subcutaneous emphysema, occurring with the various methods of escape are given in Table I.

RESULTS

In order to establish a complete record of the over-pressurization accidents connected with the two methods of escape currently being taught, the two cases of air embolism, including the one fatality, occurring during the first year of buoyant ascent training and described in Moses' report are included in this report.

TABLE I.

Over-Pressurization Casualties and Fatalities, Air Embolism and Extra-Alveolar Air, Escape Training Tank, Naval Submarine Base New London, Groton, Connecticut

Dates	Methods	Total No. of Runs	No. of Casualties	Incidence Rate	No. of Fatalities
1930-1957	Submarine Escape Appliance (Momsen Lung)	193,000	12	.006%	1
1947-1967	Free Ascent	17,500	17	.097%	2
1956-1966	Buoyant Ascent	132,000	15	.011%	1
1963-1966	Steinke Hood	47,000	7	.015%	0
1930-1966	All Types	389,500	51	.013%	4
1963-1982	Steinke Hood	538920	6	<.0001%	1

Table II shows the number of runs made and the number of accidents occurring each year in which the two methods have been employed Both air embolism cases and extra-alveolar air cases were considered as accidents. Any case in which both processes were involved was included in the more serious air embolism group.

TABLE II. ANNUAL NUMBER OF RUNS AND ACCIDENTS, ESCAPE TRAINING TANK, NEW LONDON, CONNECTICUT 1956 - 1966

JUL	JUN	NUMBER OF 50' BUOYANT ASCENT RUNS MADE	AIR EMBOLISM ACCIDENTS OCCURRING IN				EXTRA-ALVEOLAR AIR ACCIDENTS OCCURRING IN				RATIO OF AIR EMBOLISM ACCIDENTS TO NUMBER OF RUNS %		RATIO OF ALL ACCIDENTS TO NUMBER OF RUNS %		NUMBER OF 50' STEINKE HOOD RUNS MADE	AIR EMBOLISM ACCIDENTS OCCURRING IN				EXTRA-ALVEOLAR AIR ACCIDENTS OCCURING IN				RATIO OF AIR EMBOLISM ACCIDENTS TO NUMBER OF RUNS %		RATIO OF ALL ACCIDENTS TO NUMBER OF RUNS %
			STUDENT INITIAL QUALIF		REQUAL		INITIAL QUALIF		RETURN QUALIF							STUDENT INITIAL QUALIF		REQUALIF		STUDENT INITIAL QUALIF		REQUALIF				
JAN	56	947		0		0			0	0		.000		.000												
56	57	7,912		2		0			0	0		025		.025												
57	58	9,906		0		1			0	0		.011		.011												
58	59	9,137		0		0			0	0		.000		000												
59	60	11,684		1		0			0	0		.009		.009												
60	61	15,437		2		0			0	0		013		.013	73		0	0						.000	000
61	62	13,313		0		1			0	0		.008		.008	0										
62	63	19,692		0		1			0	0		.005		.005	388		0	0			0	0		000	.000
63	64	18,092		1		0			0	0		.006		.006	10,192		0	2			0	2		020	.039
64	65	9,556		1		0			1	0		.010		010	15,155		0	1			0	1		.007	013
65	66	7,995		2		0			0	0		.025		038	13,909		0	1			0	0		.007	.007
66	DEC	8,444		2		0			0	0		.024		.024	7,662		0	0			0	0		000	000
				11		3			1	0							0	4			0	3			
TOTAL		131,915		14				1				.0106		.0114	47 379		4				3			.007	.015

The air embolism incidence rate with the buoyant ascent method is .011% or approximately one accident per 9,400 runs. The large majority of buoyant ascent accidents, eleven out of fourteen, have occurred in Submarine School students, undergoing training for the first time. The incidence appears to be increasing in recent years. From July 1964, through December 1966, six accidents, five air embolism and one extra-alveolar air, have occurred during 26,000 buoyant ascent runs. This is an incidence of .019% for air embolism accidents or one per approximately 5,200 runs, 1.8 times as frequent as the eleven year average. It should be noted that during this last two and one-half year period only initially qualifying Submarine School students have been undergoing buoyant ascent training, as opposed to the previous years when the training was given to both initial qualifiers and requalifiers.

This incidence rate then is for a group that is composed of only initial qualifiers. Because records were not kept showing the number of runs made by initial qualifiers and requalifiers during the years when both received only buoyant ascent training, it is not possible to determine an exact incidence rate for each group. Indirect figures from Submarine School matriculation indicate that the group of initial qualifiers has represented approximately 40-60% of the total over the years when initially qualifying students and requalifiers underwent buoyant ascent training. Because the student qualifiers have sustained the large majority of accidents throughout the years, however, it would appear that the student accident incidence for buoyant ascent training is higher than for the requalifiers, and that in the past this incidence has been diluted when considered as a part of the overall annual incidence. When a program change in 1965 removed requalifiers from training in buoyant ascent, this situation became more apparent. It would seem that the initial buoyant ascent training is a relatively hazardous procedure.

The incidence for all over-pressurization accidents resulting from the use of the Steinke Hood is .015% or one per 6,750 runs. The incidence rate for embolism accidents with this method is .008% or one per 12,000 runs. These figures need amplification however, due to changes in the method of use of the appliance.

The first two air embolism cases and the two extra-alveolar air cases occurred during the first full year of training, fiscal year 1964 during a time in which the candidates were instructed to say "OK-OK" on ascent. This was a term used to demonstrate to the instructor in the water observing the ascent that the trainee was exhaling. During that twelve month period, the accident rate was in the area of one per 2,500 runs, considerably greater than with the use of buoyant ascent method. In investigating the reasons, it was observed that in saying "OK," the glottis had to be closed in order to pronounce the explosive sound of "K." During that time interval intra-pulmonary pressure was not being reduced. The use of the phrase "HO-HO-HO" was then introduced, in the spring of 1964, allowing an open glottis throughout expiration.

Since that change, two cases of air embolism and one case of extra-alveolar air production have occurred in over 26,000 Steinke Hood runs, giving an air embolization rate of one per 18,000 runs and total over-pressurization accident rate of one per 12,000 runs. In comparison the air embolism rate for buoyant ascent training is one per 9,400 runs, with the overall accident rate at one per 8,800 runs.

Interestingly, all cases of air embolism and extra-alveolar air production following the use of the Steinke Hood have occurred in persons undergoing requalification. It should be noted that when training in this method was begun in September 1963, it was given only to requalifiers. Six months later, a selected small number of Submarine School students, principally line and medical officers, also began to receive training. Since none of the runs made from September 1963 to April 1964 and only a very few of the runs made from April 1964 to April 1965 were performed by students, there was essentially no

opportunity for accidents to occur in the initially qualifying groups during the first two and one-half years of Steinke Hood training.

It has been only since the start of the fiscal year 1966 that free-breathing buoyant ascent training has been generally available to initial qualifiers. (While enlisted student training in this method began in April 1965, a subsequent Tank shutdown for overhaul prevented the start of Hood training for large numbers of students until July 1965). From that time until December 1966, approximately 8,000 Hood runs have been made by initial qualifiers and 13,500 runs by requalifiers. It is apparent that there has been too few runs made by the initially qualifying group to make any statement regarding their accident rate.

Two factors lead one to feel that the Steinke Hood accident rate for initial qualifiers will be lower under the present training method. At the present time initial qualifiers complete one free-breathing buoyant ascent run only after they have just completed two successful buoyant ascent runs. Requalifiers on the other hand make two hood runs and no buoyant ascent runs. Because of the familiarity with the safety and ease of properly executed escape procedures acquired through the successful completion of two buoyant ascent runs just prior to Steinke Hood insruction, the probability of the development of panic and breath-holding by a trainee on this third run would be at a minimum, even though he is an initial qualifier. Of probably even greater importance is the fact that any pathological air trapping occurring in a trainee would likely have produced symptoms in one of the preceding buoyant ascent runs rather than in the Hood run.

The quality of an ascent does not appear to be the determining factor in the production of air embolism. Most of these accidents have occurred in what appeared to be satisfactorily performed runs. Of the accidents occurring in buoyant ascent runs, nine occurred in what were termed good runs by observers, while the other four occurred in unsatisfactory runs. Five of the Steinke Hood runs which produced accidents were considered good, while two occurred during runs considered unsatisfactory.

Of even greater interest is the relationship between the results of pulmonary function studies and the quality of run made. These figures point to two unrelated problem areas; unsatisfactory runs, of course, but apparently even more important, air trapping not detected prior to training (3).

Pulmonary function studies have been performed on all trainees whose accidents occurred following Steinke Hood runs. It was learned that two of the three persons with normal studies had made unsatisfactory runs, while four of the five men who made satisfactory runs were shown to have either abnormal or questionably abnormal pulmonary functions studies, see Table III.

Table III.

Results of Pulmonary Function Studies in Persons Injured During Steinke Hood Training.

Ascent Classification	Total Cases	Pulmonary Function Studies Normal	Abnormal
Satisfactory	5	1	4
Unsatisfactory	2	2	

Abnormalities found in the studies were generally either decreased timed vital capacities or elevated nitrogen washout clearances (indicating pulmonary expiratory obstructive problems). Due to the lack of pulmonary function studies on cases of individuals sustaining over-pressurization accidents following buoyant ascent, a comparison cannot be made at this time.

There has been one fatality among the fifteen accidents occurring at Groton, Connecticut, Escape Training Tank as a result of buoyant ascent training. It occurred in 1957 during the first year of buoyant ascent training. The run appeared to be normal. There have been no deaths associated with the use of the Steinke Hood in training.

Description of the types of treatment given for air embolism, using either the standard Navy Recompression Treatment Tables 3 and

4, or the new rapid recompression high-pressure oxygen approach, now known as Tables 5A and 6A, are the subject of another report (1).

SUMMARY

Results of a study of over-pressurization accidents occurring at the Escape Training Tank, Submarine Base, Groton, Connecticut, are reported. Discussion is presented as to whether the increased accident rate following buoyant ascent runs is real or apparent. Reasons for the high accident rate with the Steinke Hood when this training was first introduced and the reason for the occurrence of accidents only in requalifiers with the Steinke Hood are offered. Data indicating the accidents are the result of two different problems, (either improper runs, or pulmonary air-trapping) acting independently, are presented. A synopsis of each over-pressurization accident occurring during the period 1956-1966 is given in Appendix A.

REFERENCES

1. Van Genderen, L. and Waite, C. L., Rapid Recompression, High-Pressure Oxygen Breathing Approach in the Treatment of Traumatic Air Embolism, SubMedResLab (SubMedCen) Report, (in preparation).
2. Moses, H, Casualties in Submarine Escape Training, SubMedResLab (SubMedCen) Report No. 438, Oct 1964 (Qual. Thesis of 1957).
3. Liebow, Stark, Vogel, and Schaefer, Intrapulmonary Air Trapping in Submarine Escape Training Casualties, SubMedResLab (SubMedCen) Report No. 330, Feb 1960.

APPENDIX A

OVER PRESSURIZATION ACCIDENTS
ESCAPE TRAINING TANK
NAVAL SUBMARINE BASE NEW LONDON
GROTON, CONNECTICUT
1957 - 1966

KEY: A = AIR EMBOLISM, S = EXTRA-ALEVOLAR AIR, X = FATALITY, B.A. = BUOYANT ASCENT RUN
S.H., O.X. = STEINKE HOOD RUN USING "OK OK", S.H., HO = STEINKE HOOD RUNS USING "HO HO HO", F.A. = FREE ASCENT
I = INITIAL QUALIFIER, R = REQUALIFIER, M.C., O.B. = MINIMAL RECOMPRESSION, OXYGEN BREATHING, TVC = TIMED VITAL CAPACITY

CLASS	CASE #	DATE	NAME	HIST OF TRNG	ASCENTS IMMED PRECED	ACCIDENT ASCENT	QUALITY OF ASCENT	SIGNS & SYMPTOMS	TREATMENT TABLES	POST-ACCIDENT PULMONARY EVALUATION	REMARKS
AS	1	8 Mar 57	Stroman, D.L.	I	18' BA 50' BA	50' BA	Good	Unconsciousness, Paralysis, Pneumothorax, Mediastinal Emphysema	IV	X-ray showed equivocal emphysematous blebs	Major recovery after 13 min at 165'
AX	2	24 Apr 57	Hadley, R.L.	I	18' BA 50' BA	50' BA	Poor Exhalation	Unconsciousness, Rigidity Gasping Respirations	165 '4-min then 220 '1-min		Dead after 8 minutes of pressurization
A	3	29 Apr 57	Hyde, W.J.	R	18' BA	50' BA	Good	Left Leg Paresis and Hyperthesia	III	Unknown	Major recovery at 100 feet on recompression
A	4	2 Jun 60	Lichty, G.L.	I	50' BA	50' BA	Good	Right Leg Paralysis Restriction of Visual Field	III	Irregular 9 Min N_2 Washout Curves	Major recovery at 100 feet on recompression. Complete recovery after 25min at 165'
A	5	4 Nov 60	Dickey, L.E.	I	None	50' BA	Good	Right Hemiparalysis	III	Normal	Recovery at 125' on recompression
A	6	23 Aug 60	Williams, J.R.	I	50' BA	50' BA	Good	Unconsciousness	1. 170/40 2. III	Abnormal	1. Recurrence of symptoms at 30 ft on 170/40 2. Major Recovery after 30min at 165'
A	7	10 Nov 60	Gynn, T.N.		None	25' FA	Good	Right Facial Paralysis Right Internal Strabismus, Protrusion of Tongue to Right	III	Generally Normal	Major recovery at 100 feet of recompression
A	8	12 Oct 61	Christenson, R.W.	R	50' BA 85' BA	85' BA	Metered Exhalation	Left Hemiparesis Dizziness at 30 ft on R_x Convulsion at 100 ft on R_x	III to 30' IV	Unknown	Initial recovery after 20 min at 165'. Nembutal + Urevert given after convulsion
A	9	2 Jul 62	Arnold, R.N.	R	None	50' BA	Good	Unconsciousness	III	Unknown	Major recovery on reaching 165'
A	10	10 Oct 63	Benson, J.W.	R	None	50' SH OK	Unsat	Left upper paresis	III	Normal, including T.V.C. and Max. Exp. Capacity	Major recovery after 10-20 min at 165'
AS	11	2 Mar 64	Odell, S.A.	R	50' SH OK	50' SH OK	Good	Right upper paresis Subcutaneous Emphysema Pneumopericardium	III	Normal	Major recovery at 130 ft of recompression

CLASS	CASE #	DATE	NAME	HIST OF TRNG	ASCENTS IMMED PRECED.	ACCIDENT ASCENT	QUALITY OF ASCENT	SIGNS & SYMPTOMS	TREATMENT TABLES	POST-ACCIDENT PULMONARY EVALUATION	REMARKS
S	12	9 Mar 64	Cross, T E.	R	None	50' SH OK	Good	Mediastinal Emphysema Pneumopericardium	None	Abnormal, including N_2 clearance	
AS	13	13 Mar 64	Kauf, R.C	I	50' BA	50' BA	Metered Exhalation	Unconsciousness Subcutaneous Emphysema Left Pneumothorax	III	Abnormal, elevated exp./insp. time & insp. capacity spiking	Major improvement present prior to recompression
S	14	17 Mar 64	Hernandez, F.	R	None	50' SH OK	Unsat.	Left pneumothorax Mediastinal Emphysema	None	Normal	
S	15	8 Sep 64	Zehren, D.E.	R	50' SH HO	50' SH HO	Good	Right Pneumothorax	None	Abnormal reduced TVC	Treatment with water-seal vacuum
A	16	15 Oct 64	Miller, M.H.	I	None	50' BA	Metered Exhalation	Collapse, Left Spasticity, Right Flaccidity	Modified Old Short V	Normal	Major recovery after 11 min at 165'
A	17	11 Mar 65	Norris	R	None	50' SH	Good	Left Hemiparalysis	Modified M.C.O.B. 165', 30'	Abnormal high N_2 washout curves & reduced TVC	Major recovery after 10 min at 165'. Tender devolved bends on this schedule.
S	18	4 May 65	Reynolds, L.D.	I	50' BA	50' BA	Good	Right Pneumothorax	None	Normal, including one min N_2 washout and TVC	Mild chest pain also occurred after first run
A	19	6 Jan 66	Travisano, B.S.	R	50' SH HO	50' SH HO	Good	Back Pain and Collapse	170 ft for 20 min table	Abnormal TVC	Major recovery between 60 & 100 ft of recompression
A	20	26 May 66	Defrain, J.H.	I	50' BA	50' BA	Good	Unconsciousness, Right Facial Paralysis	Modified M.C.O.B 165', 60', 30'		Major recovery after 2 min at 165'
A	21	15 Jun 66	Helms, J.D.	I	None	50' BA	Intermittant Exhalation	Unconsciousness	Modified M.C.O.B 165', 60', 30'		Major recovery after 15 min at 165'
AS	22	23 Sep 66	Beall, F J.	I	50' BA	50' BA	Metering Exhalation	Stupor, Right Paralysis Pneumopericardium	Modified New Short V		Major recovery after 10 min at 165'. Pneumopericardium Symptoms began after first run.
A	23	24 Oct 66	Madsen, D.D.	I	None	50' BA	Good	Bilateral Upper Paresis and Paresthesia	Modified New Short V		

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13 ABSTRACT

This report is an extension of Moses' study of casualcies resulting from submarine escape training during the period 1928-1957 (SMRL Report No. 438). A total of 23 additional over-pressurization accidents are presented, along with discussion as to whether the increased accident rate following introduction of buoyant ascent runs is real or apparent.

Reasons are advanced for the high accident rate with the Steinke Hood when this type of training was first introduced, and reasons are given for the occurrence of accidents in re-qualifiers as opposed to the student trainees. Some of the casualties are attributed to lung abnormalities leading to pulmonary air-trapping, which causes symptoms to develop after seemingly successful training runs.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Buoyant ascent in submarine escape training						
Submarine escape training						
Pulmonary air-trapping in submarine escape training						